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Technical Report AEC-TR-76-01

DYNAMIC RESPONSE OF MISSILE STRUCTURES TO IMPULSIVE LOADS CAUSED BY NUCLEAR EFFECTS BLOWOFF

by

Thomas L. Cost

June 1976

Final Report On

Contract DAAH01-76-C-0293

Prepared for

Ground Equipment and Materials Directorate
US Army Missile Research
Development and Engineering Laboratory
US ARMY MISSILE COMMAND
REDSTONE ARSENAL, ALABAMA 35809

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Two dynamic structural analysis computer codes have been developed for the analysis of missile type structures subjected to impulsive loads produced by nuclear effects blowoff. One code, IMPLATE, is applicable to flat plate structures prestressed by inplane mechanical and thermal loads and the other code, IMPSHELL, can be applied to thin cylindrical shell type structures preloaded by internal pressure. The impulsive loads are calculated with the aid of a photoelectric energy deposition code, — over

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20. ABSTRACT (Continued)

KNISH, and a blowoff model. A theory for correlating the nuclear effects blowoff impulse with impulse produced by a laboratory simulation "exploding foil" technique is presented.

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FOREWORD

The two computer programs described in this report were developed by Athena Engineering Company under Contract DAAH01-76-C-0293 with the U.S. Army Missile Command, Redstone Arsenal, Alabama. The development was sponsored and technically monitored by the Ground Equipment and Materials (GEM) Directorate, US Army Missile Research, Development, and Engineering Laboratory. Dr. Bobby Mullinix, GEM Directorate, served as the Contracting Officer's Technical Representative and technically monitored all work on the project. The two computer codes, IMPLATE and IMPSHELL, are operational on the MICOM CDC 6600 computer system and on a UNIVAC 1108 system used by Athena Engineering Company. The codes are written in Fortran and should operate satisfactorily on all equivalent computer systems. Copies of the computer code, either on cards or tape, may be obtained upon request from the contract sponsor.

TABLE OF CONTENTS

1. INTRODUCTION

During a nuclear engagement outside the atmosphere a severe threat to the structural integrity of missile structures is posed by the x-ray component of the radiant energy emission from a nuclear weapon detonation. When the levels of absorbed energy are sufficiently high, sublimation of the outer structural surface can occur with a resulting impulsive load being imparted to the structure. This impulsive load can produce stress waves in the structure or gross structural response or both. Although the influence of the stress waves on structural integrity has been studied widely (1-3), the influence of the impulsive loads on the longer-time structural response has received less attention (4,5).

The objective of this project was to develop an ability to study the structural response of isotropic, metallic, flat plate and cylindrical structures subjected to impulsive loads produced by x-ray induced material sublimation. It is assumed in this study that the material remains elastic and that the x-rays damage the structure by decreasing the structural thickness where sublimation occurs. Temperature influence on material properties is neglected for simplicity.

To accomplish this objective, a flat plate structural response code, QTRPLATE, used in experimental studies at the U.S. Army Missile Command (6) was modified to accommodate x-ray deposition loads and a cylindrical shell code, IMPSHELL, developed for predicting structural response to such loads.

2. IMPULSIVE LOAD CALCULATION

The radiant energy component of a nuclear weapon detonation can sublimate the surface layer of structures exposed to the energy flux provided the fluence is sufficiently high. This extremely rapid sublimation can produce impulsive loads on the structure due to the momentum transfer resulting from the rapid movement of the surface particles. The impulsive loads induce structural motion and associated stresses, strains, and deformations.

2.1 General Computational Method

The Whitener (11) analytical model has been incorporated into both the flat plate and circular cylinder structural response codes described in Sections 3. and 4., respectively. The Whitener model requires a knowledge of the energy deposition profile through the thickness of the exposed structure along with appropriate physical properties. The model can be expressed as

$$I_B = \sum_{j=1}^{n} (\rho \Delta x)_j \sqrt{2F_c(H-E_s)_j} \qquad (2.1)$$

where:

I_B = blowoff impluse,* taps/cm^2

ρ_j = density of zone j, g/cm^3

Δx_j = thickness of zone j, cm

H_j = total energy deposited in zone j, cal/g

E_s = sublimation energy for the material, cal/g

n = number of zones

F_c = conversion factor, 4.186×10^7 ergs/cal

$(H-E_s)_j$ = excess energy in zone j

---

* A tap is 1 bar - microsecond.

To implement this model the distribution of the deposited energy through the thickness of the structure must be known.

2.2 KNISH Computer Code

The KNISH photon deposition computer program (7) used to compute the energy deposition profiles for use in the Whitener model has evolved from a code written by Dr. John Huntington at the Moleculon Company for the Defense Atomic Support Agency (DASA) in 1968. The code was modified by the Physics International Company in 1972. The code treats Compton single scattering and photoelectric energy deposition in an axisymmetric slab geometry.

The input-output operations of the KNISH code have been modified for use in the codes described here to make data input more concise and to permit direct use of the output in the Whitener model for impulse calculations. The following simplifications have been made in data input:

1) the spectrum energy mesh is computed internally by a prescribed formula which takes into account the characteristic temperature of the nuclear weapon detonation,
2) only spectra formed by superimposing individual blackbody spectra are permitted,
3) the number of regions in the structure is preset to one,
4) the number of dose points is set internally in the code to fifty.

This information is provided to relate the simplifications made in KNISH input procedures to the original code described in Reference 7. Data input descriptions for the flat plate code IMPLATE and cylindrical shell code IMPSHELL are described in Sections 3.3 and 4.3, respectively.

The accuracy of KNISH was investigated by comparing the accuracy of energy deposition profiles computed with KNISH with standard results.

Such a comparison for copper is illustrated in Figure 2.1 for various blackbody temperatures. As can be seen from the figure, good accuracy is obtained using KNISH for all blackbody temperatures. The printed output from KNISH for this case is contained in Table 2.1.

2.3 Flat Plate Model

As illustrated in Figure 2.2, the radiant energy striking the flat plate is assumed to occur normal to the plate and be uniformly distributed. For purposes of impulse calculation the plate is assumed divided into various regions or zones through the thickness. These zone descriptions are preset in KNISH and used to calculate the energy deposition profile. From a knowledge of this profile the thickness of the sublimated layer is determined by noting where in the structure the deposited energy intensity exceeds the sublimation energy. All material absorbing energy at levels higher than the sublimation energy will be sublimated. This condition is illustrated schematically in Figure 2.3.

Once the deposition profile and thickness of the sublimated layer is determined, the Whitener model, Eq. 2.1, can be used to compute the total impulse in taps per cm^2. The impulse is assumed imparted to the structure by a uniform pressure load which varies linearly with time as illustrated in Figure 2.4, where t_s, the "shine time", is input as data. The maximum pressure P is computed by use of the equation

$$P = 2I_B/t_s \tag{2.2}$$

where I_B is computed using Eq. 2.1.

2.4 Cylinder Model

Radiant energy is assumed to impinge on the cylindrical shell model as indicated in Figure 2.5a. Only the component of the energy normal to the surface is assumed to be absorbed in the cylindrical structure. This causes the resulting impulse to be imparted to the structure in a nonuniform manner as indicated in Figure 2.5b. The same procedure

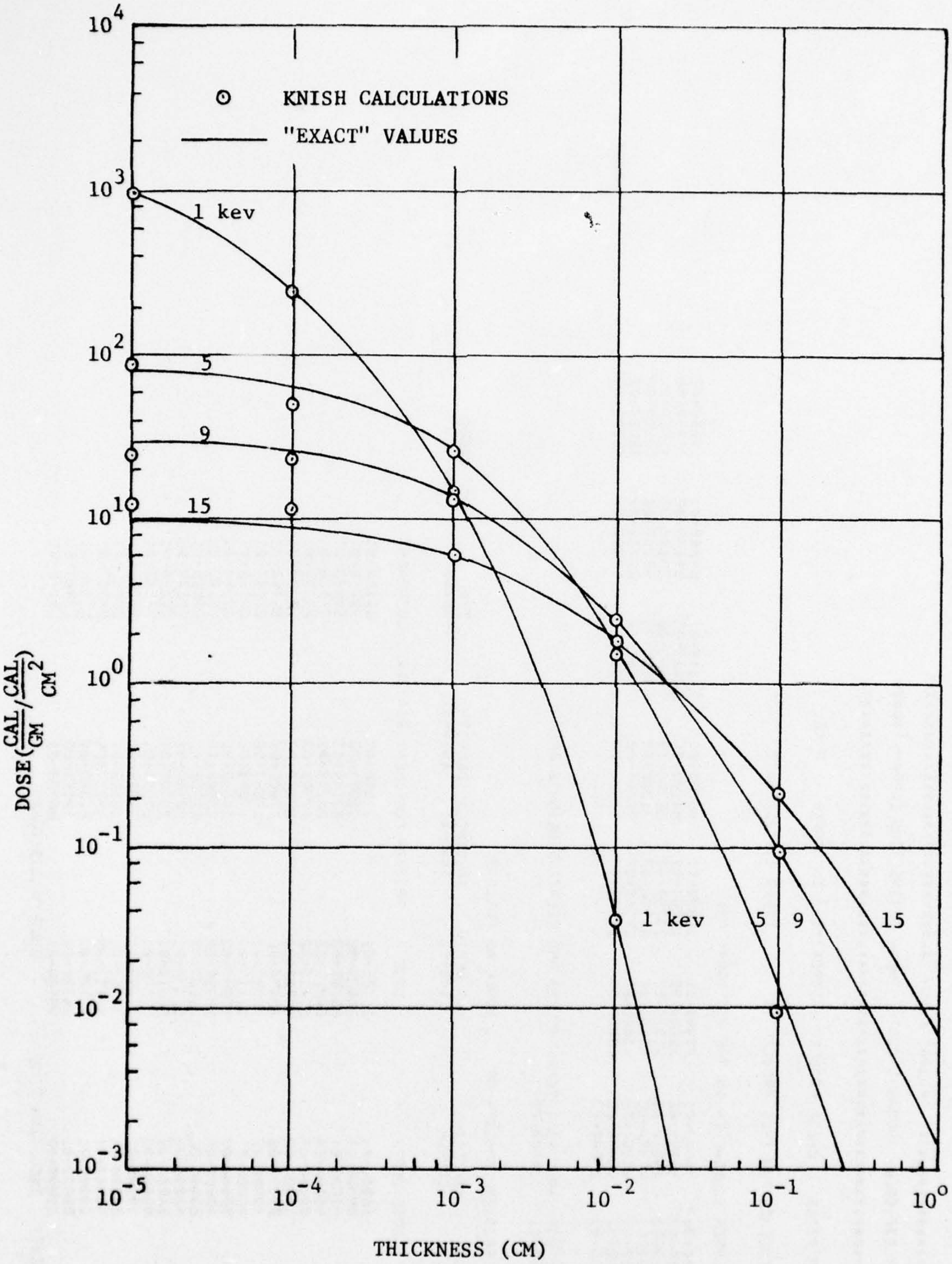


Figure 2.1. Energy Deposition in Copper

TABLE 2.1 ENERGY DEPOSITION IN COPPER

```
#################### PROGRAM KNISH ###########################
##### MODIFIED BY THOMAS L COST. ATHENA ENGINEERING COMPANY #####
###############################################################

PROBLEM TITLE    CHECK PROBLEM - DEPOSITION IN COPPER -  9 KEV

  THE FLUENCE FOR THIS PROBLEM IS       10000+01 CAL/CM**2

  THE UPPER BOUNDARIES ON THE HISTOGRAM ARE
```

90000+00	18000+01	27000+01	36000+01	45000+01	64500+01	84000+01	10350+02
12300+02	14250+02	16200+02	18150+02	20100+02	22050+02	24000+02	25950+02
27900+02	29850+02	31800+02	33750+02	35700+02	37650+02	39600+02	41550+02
43500+02	45450+02	47400+02	49350+02	51300+02	53250+02	55200+02	57150+02
59100+02	61050+02	63000+02	67500+02	72000+02	76500+02	81000+02	85500+02
90000+02	99000+02	10800+03	11700+03	12600+03	13500+03	14400+03	15300+03
16200+03	27000+03						

```
  BLACK BODY SPECTRUM  TEMPERATURES AND RELATIVE WEIGHTS ARE
   90000+01     10000+01

  THIS PROBLEM CONSISTS OF    1 ZONES AS FOLLOWS
```

ZONE NO	MATERIAL	FAR DEPTH	THICKNESS	DENSITY	Z/A	NO EDGES
1	COPPER	1000+01	1000+01	8940+01	4560+00	30

DOSE DEPTH	DOSE	PRIMARY COMPONENT	SCATTERED COMPONENT
10000-04	31721+02	31662+02	59180-01
20000-04	30629+02	30570+02	59710-01
40000-04	29208+02	29148+02	60663-01
60000-04	28219+02	28158+02	61506-01
80000-04	27413+02	27350+02	62258-01
10000-03	26703+02	26640+02	62933-01
20000-03	23874+02	23809+02	65452-01
40000-03	19922+02	19854+02	68062-01
60000-03	17117+02	17048+02	69158-01
80000-03	15003+02	14933+02	69554-01
10000-02	13355+02	13286+02	69583-01
20000-02	86660+01	85982+01	67828-01
40000-02	51338+01	50709+01	62840-01
60000-02	36314+01	35731+01	58254-01
80000-02	27872+01	27329+01	54246-01
10000-01	22433+01	21926+01	50732-01
20000-01	10550+01	10169+01	38049-01
40000-01	42693+00	40237+00	24557-01
60000-01	23125+00	21382+00	17436-01
80000-01	14330+00	13023+00	13066-01
10000+00	96169-01	86022-01	10146-01

```
NORMAL EXIT   EXECUTION TIME        5962 MILLISECONDS
>
```

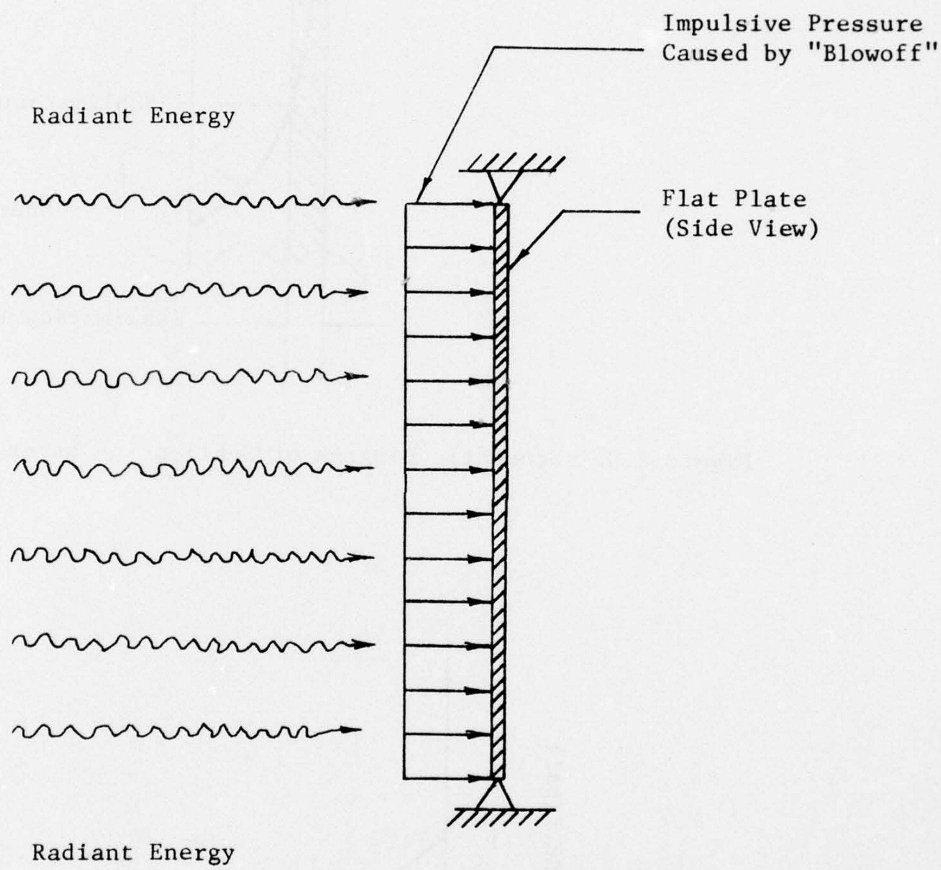


Figure 2.2. Schematic Diagram of Impulsive Loading of a Flat Plate

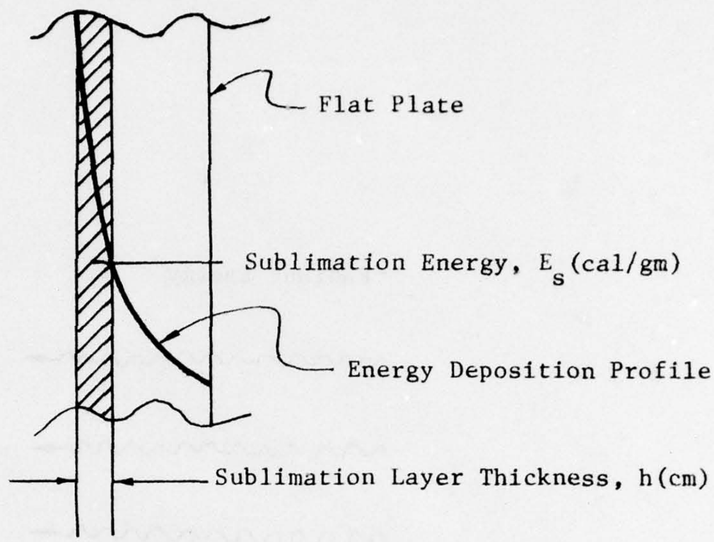


Figure 2.3. Schematic Diagram of Sublimation Layer in Flat Plate

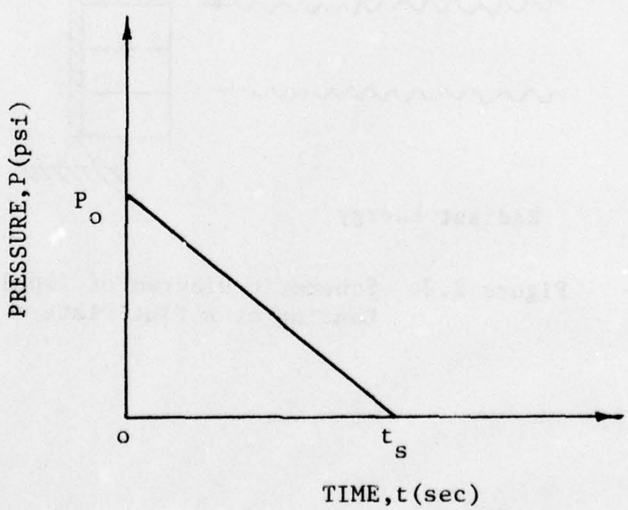


Figure 2.4. Time Variation of Blowoff Pressure

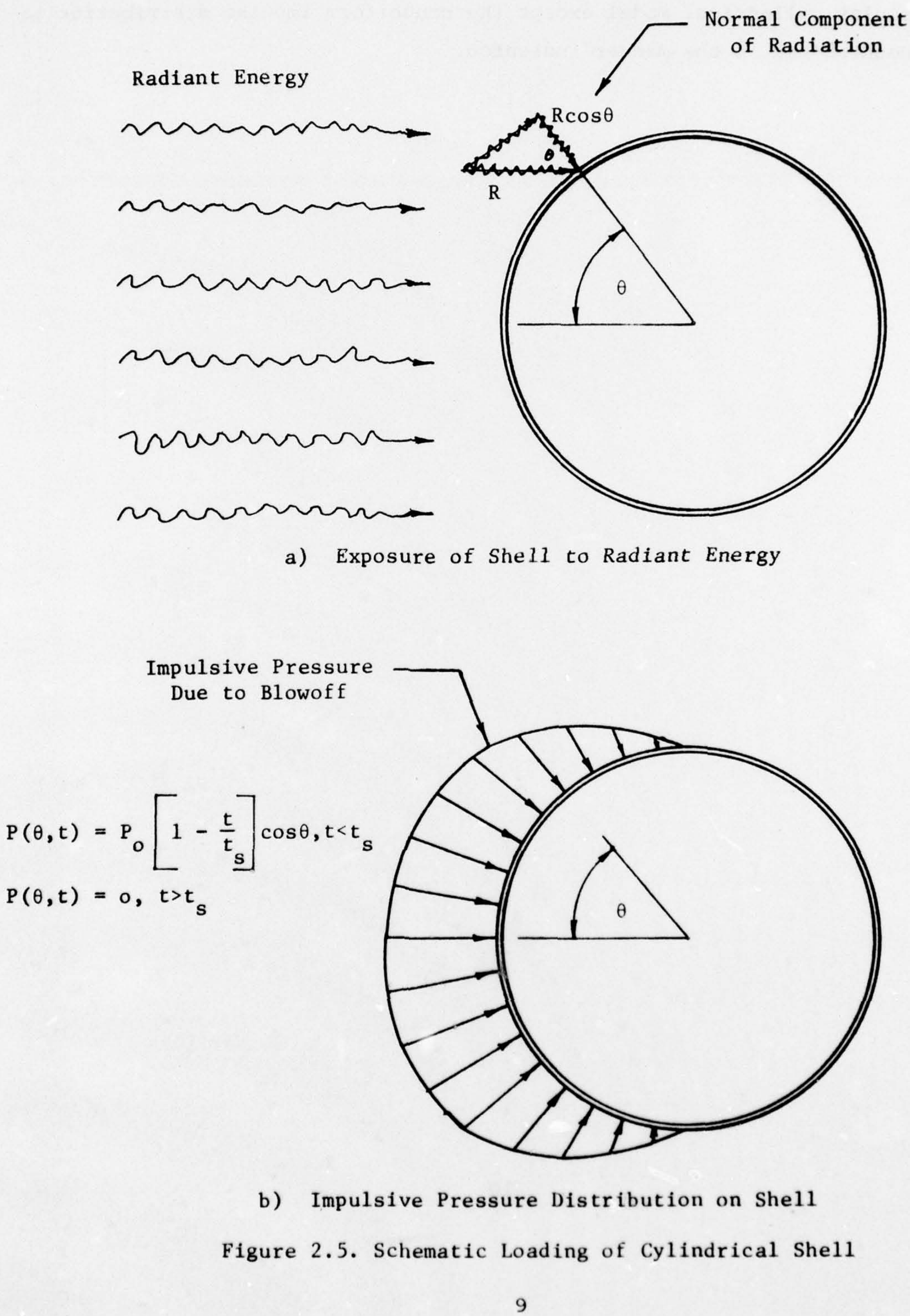


Figure 2.5. Schematic Loading of Cylindrical Shell

used in the flat plate model to calculate the impulse is used for the circular cylindrical model except the nonuniform impulse distribution is accounted for in the manner indicated.

3. FLAT PLATE RESPONSE CODE

3.1 Description

The computer code QTRPLATE, developed previous to this work (6), is designed to predict the dynamic response of flat plates to air blast loads while, simultaneously, prestressed by inplane thermal and mechanical loads. The code implements a finite difference solution to the governing equations of motion which are based upon small deformation theory and linear elastic material behavior. A mode superposition and shock spectrum approach is used to compute peak values for the stresses, strains, and displacements in the plate. Predicted response has been shown to agree closely with experimental results (8).

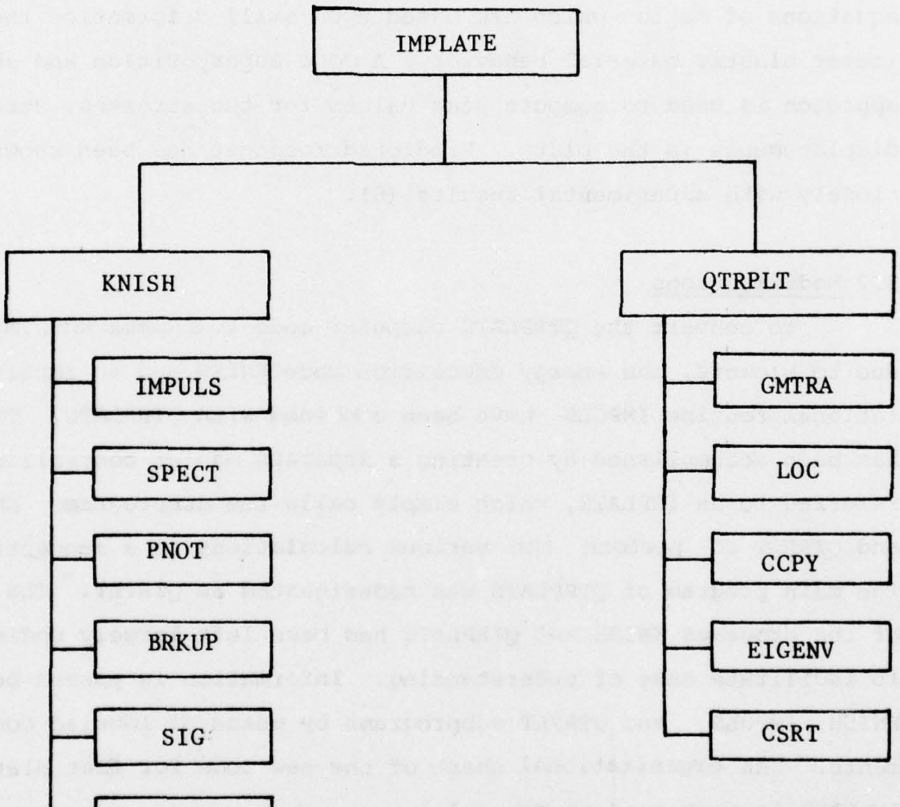
3.2 Modifications

To convert the QTRPLATE computer code to accommodate impulse loads due to blowoff, the energy deposition code KNISH and an impulse computational routine IMPULS have been combined with QTRPLATE. The combination has been accomplished by creating a separate master controlling program, referred to as IMPLATE, which simply calls the subprograms KNISH, IMPULS, and QTRPLT to perform the various calculations in a sequential manner. The main program of QTRPLATE was redesignated as QTRPLT. The integrity of the programs KNISH and QTRPLATE has been left largely undisturbed to facilitate ease of understanding. Information is passed between the KNISH, IMPULS and QTRPLT subprograms by means of labeled common statements. An organizational chart of the new code for flat plate response IMPLATE is contained in Table 3.1.

The most significant modification made to the code QTRPLATE involved modification of the subroutine SPCTRM. The displacement shock spectrum, defined for each generalized coordinate of the flat plate, is defined as (6),

$$F_i\ (\omega_i) = \max_{t>o} \left| \frac{1}{M_i \omega_i} \int_o^t P(\tau)\ \sin\ \omega_i (t-\tau) d\tau \right| \qquad (2.3)$$

Table 3.1 ORGANIZATIONAL CHART FOR IMPLATE



where M_i is the generalized mass, ω_i the natural frequency associated with the i_{th} degree of freedom, and $P(t)$ is the pressure intensity. Using the expression for the pressure contained in Figure 2.4, the value for $F_i(\omega_i)$ can be expressed as

$$F_i(\omega_i) = \frac{P_o(2+t_s\omega_i)}{t_s M_i \omega_i^3} \tag{2.4}$$

The value of FMAX in subroutine SPCTRUM has been modified to reflect this change.

In addition to the above changes, minor modifications have been made in the input/output procedures. These changes will be described in the following section.

3.3 Data Input Format

Data is input to the computer code IMPLATE by specifying information on punched cards as follows:

1. Title card
2. Fluence card
3. Spectrum definition cards
4. Material identification card
5. Photoelectric cross-section cards
6. Plate geometry and edge restraint card
7. Material property card
8. Mechanical and thermal preload card

If several problems are to be run sequentially, cards 1 through 8 should be prepared for each problem and stacked sequentially. Normal termination of a run stream is accomplished by placing a card with the letters END in the first three columns at the end of the stacked deck. Details of the information to be specified in cards 1 through 8 above are contained in Table 3.2.

TABLE 3.2 DATA CARD DESCRIPTION FOR IMPLATE

Card	Columns	Format	Data Item
1	1-80	80A1	TITLE - Any alphanumeric characters chosen to describe problem
2	1-10	E10.0	FLOONZ - Fluence (cal/cm^2)
	11-12	E10.0	SHINET - "Shine time" (μs)
3	1-10	E10.0	TT - Blackbody temperature (kev)
	11-12	E10.0	FF - Decimal fraction of total fluence at temperature TT
			Repeat cards of type 3 for as many blackbody spectra needed (5 maxium). End cards with a blank card.
4	1-10	10A1	ZMAT - Material name
	11-20	E10.0	DD - Material density (g/cm^3)
	21-30	E10.0	ZZ - Ratio of atomic number to atomic weight
	31-40	I10	NED - No. of cards containing photoelectric cross-sections
	41-50	E10.0	ES - Sublimation energy (cal/gm)
5	1-10	E12.0	A1 - Coefficient in cross-section equation
	11-20	E12.0	B1 - Coefficient in cross-section equation
	21-30	E12.0	U - Upper photon energy limit
6	1-10	F10.0	A - Plate width (cm)
	11-20	F10.0	H - Plate thickness (cm)
	21-26	1A6	BC - Boundary conditions (CC or SS)
7	1-10	F10.0	E - Young's modulus (GN/m^2)
	11-20	F10.0	ANU - Poisson's ratio
	21-30	F10.0	ALPHA - Thermal expansion coefficient, (1/°F)
	31-40	F10.0	RHO - Plate density (g/cm^3)
8	1-10	F10.0	TX - x-tension (N/cm)
	11-20	F10.0	TY - y-tension (N/cm)
	21-30	F10.0	TEMP - temperature (°F)

3.4 Sample Problem

To illustrate the punched card format, consider the problem in which a square, aluminum plate, 10 X 10 X 0.16 cm is subjected to an inplane tension preload in the x-direction of magnitude 20 N/cm, an inplane tension preload in the y-direction of 10 N/cm, and is heated to a temperature 20°F above the reference state. Finally, the plate is subjected to a fluence of 75 cal/cm^2, from a nuclear weapon with a blackbody spectrum and a temperature of 5 kev. The shine time of the nuclear weapon is 300. microseconds. Young's modulus for the aluminum is 68.95 GN/m^2, Poisson's ratio is 0.3, the density 2.71 g/cm^3, and the thermal expansion coefficient is 4.0×10^{-6}/°F. The material photoelectric cross-section and atomic number properties are contained in Table 3.3. The plate is assumed to have all edges clamped. The data cards to run this problem are listed in Table 3.3.

The computer code IMPLATE computes the natural frequencies and mode shapes for the prestressed plate and uses these in a spectral analysis method to determine a conservative estimate of the maximum deflections, stresses, and strains in the plate. This information is printed out along with a description of the input data. The results of the sample problem described above are presented in Table 3.4.

TABLE 3.3 DATA CARDS TO EXECUTE IMPLATE SAMPLE PROBLEM

```
  IMPLATE SAMPLE PROBLEM. 7079 AL PLATE. 75 CAL/CM2. 5 KEV BB
 75        300
5          1

AL 7079   2 70          0 4814         30   3065
 0 16772D 04-0 26673D 01 0 10430D 01                                   AL7079
 0 17603D 04-0 26643D 01 0 10990D 01                                   AL7079
 0 22021D 04-0 26660D 01 0 11950D 01                                   AL7079
 0 25072D 04-0 26611D 01 0 13040D 01                                   AL7079
 0 27832D 04-0 26198D 01 0 15000D 01                                   AL7079
 0 27606D 04-0 25997D 01 0 15590D 01                                   AL7079
 0 11891D 05-0 24275D 01 0 20000D 01                                   AL7079
 0 13063D 05-0 25632D 01 0 30000D 01                                   AL7079
 0 15055D 05-0 26924D 01 0 40000D 01                                   AL7079
 0 16924D 05-0 27768D 01 0 50000D 01                                   AL7079
 0 18714D 05-0 28393D 01 0 59880D 01                                   AL7079
 0 18892D 05-0 28396D 01 0 60000D 01                                   AL7079
 0 21132D 05-0 29021D 01 0 65390D 01                                   AL7079
 0 21259D 05-0 29005D 01 0 80000D 01                                   AL7079
 0 24191D 05-0 29627D 01 0 89780D 01                                   AL7079
 0 25933D 05-0 28429D 01 0 96580D 01                                   AL7079
 0 29142D 05-0 28008D 01 0 10000D 02                                   AL7079
 0 33849D 05-0 28658D 01 0 15000D 02                                   AL7079
 0 40939D 05-0 29361D 01 0 20000D 02                                   AL7079
 0 48263D 05-0 29910D 01 0 30000D 02                                   AL7079
 0 55388D 05-0 30315D 01 0 40000D 02                                   AL7079
 0 59471D 05-0 30508D 01 0 50000D 02                                   AL7079
 0 61331D 05-0 30586D 01 0 60000D 02                                   AL7079
 0 62235D 05-0 30622D 01 0 80000D 02                                   AL7079
 0 60576D 05-0 30560D 01 0 10000D 03                                   AL7079
 0 55032D 05-0 30352D 01 0 15000D 03                                   AL7079
 0 45539D 05-0 29974D 01 0 20000D 03                                   AL7079
 0 33601D 05-0 29395D 01 0 30000D 03                                   AL7079
 0 21823D 05-0 28643D 01 0 40000D 03                                   AL7079
 0 14537D 05-0 27965D 01 0 50000D 03                                   AL7079
10          16              CC
68 95         0 3        000004     2 71
20          10         20
END
END DATA
>
```

```
********************  PROGRAM IMPLATE  *************************

**** DEVELOPED BY THOMAS L COST. ATHENA ENGINEERING COMPANY *****

*****************************************************************

PROBLEM TITLE    IMPLATE SAMPLE PROBLEM. 7079 AL PLATE. 75 CAL/CM2. 5 KEV BB

 THE FLUENCE FOR THIS PROBLEM IS       75000+02 CAL/CM**2

 THE UPPER BOUNDARIES ON THE HISTOGRAM ARE

  50000+00   10000+01   15000+01   20000+01   25000+01   35833+01   46667+01   57500+01
  68333+01   79167+01   90000+01   10083+02   11167+02   12250+02   13333+02   14417+02
  15500+02   16583+02   17667+02   18750+02   19833+02   20917+02   22000+02   23083+02
  24167+02   25250+02   26333+02   27417+02   28500+02   29583+02   30667+02   31750+02
  32833+02   33917+02   35000+02   37500+02   40000+02   42500+02   45000+02   47500+02
  50000+02   55000+02   60000+02   65000+02   70000+02   75000+02   80000+02   85000+02
  90000+02   15000+03

 BLACK BODY SPECTRUM. TEMPERATURES AND RELATIVE WEIGHTS ARE
  50000+01   10000+01

 THIS PROBLEM CONSISTS OF    1 ZONES AS FOLLOWS

ZONE NO        MATERIAL            FAR DEPTH   THICKNESS  DENSITY       Z/A        NO  EDGES
  1            AL 7079              1000+00     1000+00    2700+01     4814+00       30

          DOSE DEPTH              DOSE     PRIMARY COMPONENT SCATTERED COMPONENT

           10000-04             31899+04          31852+04          46577+01
           20000-04             30905+04          30858+04          46750+01
           30000-04             30231+04          30184+04          46908+01
           40000-04             29638+04          29591+04          47054+01
           50000-04             29084+04          29037+04          47189+01
           60000-04             28561+04          28513+04          47315+01
           70000-04             28065+04          28018+04          47434+01
           80000-04             27595+04          27548+04          47546+01
           90000-04             27149+04          27101+04          47653+01
           10000-03             26725+04          26678+04          47756+01
           12000-03             25939+04          25891+04          47948+01
           14000-03             25225+04          25176+04          48127+01
           16000-03             24574+04          24525+04          48295+01
           18000-03             23978+04          23930+04          48454+01
           20000-03             23431+04          23383+04          48605+01
           22000-03             22927+04          22878+04          48750+01
           24000-03             22461+04          22412+04          48888+01
```

Table 3.4 OUTPUT FROM IMPLATE SAMPLE PROBLEM (continued)

26000-03	22029+04	21980+04	49022+01
28000-03	21626+04	21577+04	49150+01
30000-03	21260+04	21201+04	49275+01
32000-03	20898+04	20848+04	49395+01
34000-03	20567+04	20517+04	49512+01
36000-03	20255+04	20205+04	49625+01
38000-03	19961+04	19911+04	49735+01
40000-03	19682+04	19633+04	49843+01
50000-03	18488+04	18431+04	50342+01
60000-03	17517+04	17467+04	50789+01
70000-03	16716+04	16665+04	51193+01
80000-03	16033+04	15981+04	51562+01
90000-03	15439+04	15387+04	51299+01
10000-02	14916+04	14863+04	52210+01
20000-02	11640+04	11595+04	54304+01
30000-02	98619+03	98067+03	55268+01
40000-02	86372+03	85816+03	55605+01
50000-02	77130+03	76575+03	55558+01
60000-02	69769+03	69217+03	55267+01
70000-02	63699+03	63151+03	54817+01
80000-02	58570+03	58028+03	54262+01
90000-02	54161+03	53625+03	53641+01
10000-01	50321+03	49791+03	52977+01
20000-01	28354+03	27893+03	46156+01
30000-01	18954+03	18548+03	40615+01
40000-01	13929+03	13570+03	35942+01
50000-01	10849+03	10528+03	32051+01
60000-01	87725+02	84867+02	28583+01
70000-01	72782+02	70245+02	25354+01
80000-01	61505+02	59285+02	22200+01
90000-01	52686+02	50795+02	18914+01
10000+00	45564+02	44050+02	15141+01

IMPULSE DESCRIPTION

SUBLIMATION LAYER THICKNESS (CM)	=	00002000
IMPULSE (TAPS)	=	4 00753045
IMPULSE (N-MICROSECONDS/M2)	=	400753 04296875
MAXIMUM PRESSURE (N/M2)	=	2671 68695068

Table 3.4 (continued)

```
DYNAMIC RESPONSE OF AN ELASTIC SQUARE PLATE
PRESTRESSED BY MECHANICAL AND THERMAL LOADS AND SUBJECTED
TO AN EXPONENTIALLY DECAYING BLAST LOADING


 INPLATE SAMPLE PROBLEM. 7079 AL PLATE. 75 CAL/CM2. 5 KEV BB

A (X-WIDTH)     =      100000  M

THICKNESS       =      001600  M

BOUNDARY CONDITIONS =     CC

MODULUS         =    68949999616  N/M2

POISSON RATIO =        3000

THERMAL COEF    =    0000040 1/DEGREES F

DENSITY         =      0000027100 KG/M3

TENSION-X       =      1999999993 N/M

TENSION-Y       =      0999999996 N/M

TEMPERATURE     =      20 00 DEGREES F

PRESSURE        =      2671 68695 N/M2

TIME CONSTANT =

THE NUMBER OF MODES CONSIDERED  =   6
```

Table 3.4 (continued)

REAL EIGENVALUES	FREQUENCIES IN CPS
24706433+00	39101790+08
26804920+01	12879496+09
26885742+01	12898899+09
75491892+01	21614330+09
93119614+01	24005580+09
93647850+01	24073571+09
15979933+02	31446990+09
16003736+02	31470403+09
17404882+02	32819137+09
17602244+02	33004688+09
26372529+02	40398711+09
26429686+02	40442465+09
32059961+02	44542348+09
44211874+02	52307152+09
44280228+02	52347572+09
58937926+02	60393338+09

Table 3.4 (continued)

IMPLATE SAMPLE PROBLEM. 7079 AL PLATE. 75 CAL/CM2. 5 KEV BB

STRAIN. STRESS. AND DISPLACEMENT FOR MIDLINE STATIONS

NODE	STATION COORDINATE	X-STRAIN (CM/CM)	Y-STRAIN (CM/CM)	XY-STRAIN (CM/CM)	X-STRESS (N/M2)	Y-STRESS (N/M2)	XY-STRESS (N/M2)	DISPLACEME (M)
1	012	-.972-05	408-05	.000	- 852+07	- .779+07	.000	.419-05
2	025	.746-05	103-04	000	- .708+07	- 693+07	000	103-04
3	037	148-04	154-04	000	- 641+07	- 637+07	.000	.140-04
4	050	178-04	175-04	.000	- 614+07	-.615+07	000	.166-04
5	062	148-04	154-04	.000	-.641+07	- 637+07	000	.140-04
6	075	746-05	103-04	000	- 708+07	- 693+07	000	.103-04
7	087	- 972-05	408-05	000	- 852+07	- 779+07	000	.419-05

END DATA

Table 3.4 (continued)

4. CYLINDRICAL SHELL RESPONSE CODE

4.1 Description

A computer code, designated as IMPSHELL, has been developed to predict the dynamic response of a linear, elastic cylindrical shell to an impulsive load produced by "blowoff". The cylindrical shell can be subjected to an internal pressure. A finite difference approximate solution method is used to solve the governing equations of motion. The code IMPSHELL uses a different solution technique from the technique used in IMPLATE. Whereas the mode superposition method is used in IMPLATE, a Newmark-Beta (12) time intergration procedure is used in IMPSHELL. This permits an exact determination of the transient response of the shell to be computed for comparison with experimental data.

4.2 Equations of Motion

Applying the principle of virtual displacements to the shell structure illustrated in Figure 4.1 permits the governing equations of motion of the cylindrical shell in the v and w directions to be expressed as

$$R(p-q)(v-w_{,\theta}) + N_{\theta,\theta}(R + v_{,\theta} + w) + N_{\theta}(v_{,\theta\theta} + 2w_{,\theta} - v) = \rho h R^2 \ddot{v} \tag{4.1}$$

and

$$R(p-q)(R+v_{,\theta}+w) + N_{\theta}(w_{,\theta\theta}-2v_{,\theta}-w-R) + N_{\theta,\theta}(w_{,\theta}-v) = \rho h R^2 \ddot{w} \tag{4.2}$$

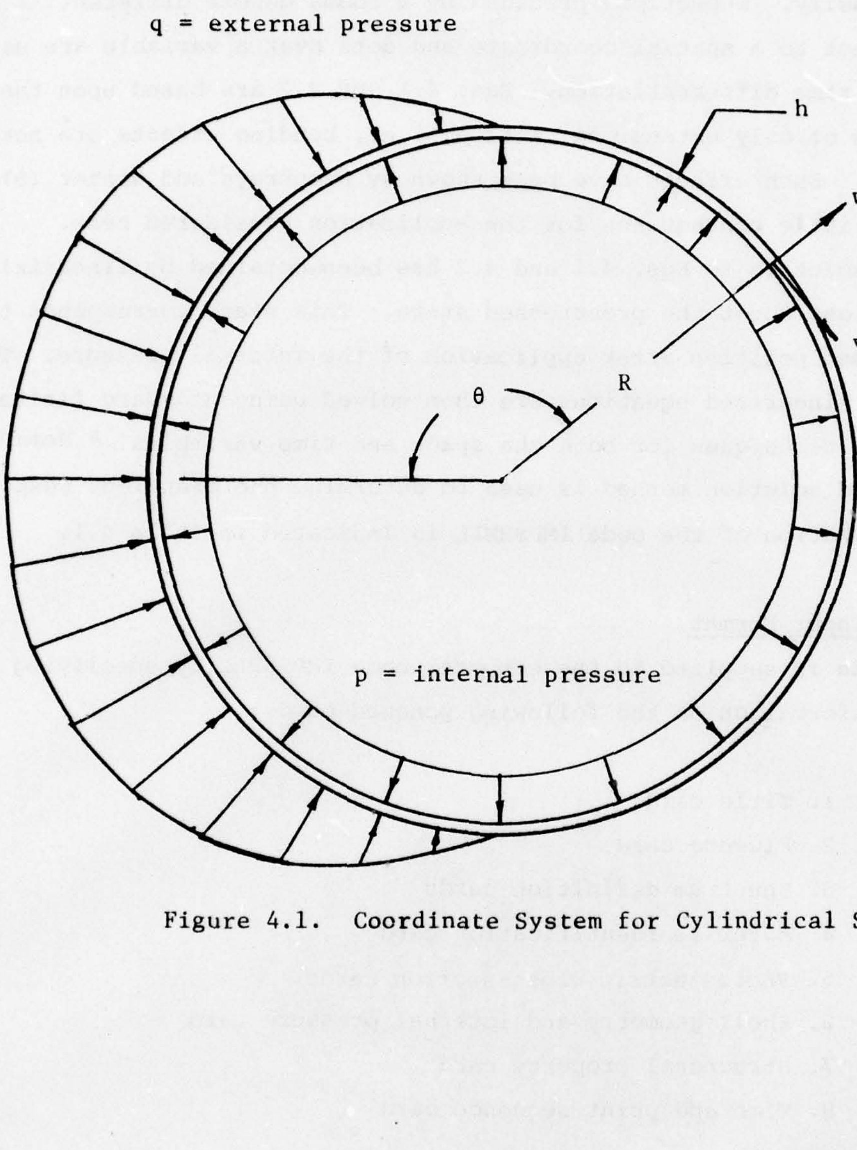


Figure 4.1. Coordinate System for Cylindrical Shell

In Eqs. 4.1 and 4.2, p, q, v, w, R, h, and θ are defined in Figure 4.2. N is the force per unit length in the circumferential direction, and ρ is the density. Subscripts preceded by a comma denote differentiation with respect to a spatial coordinate and dots over a variable are used to designate time differentiation. Eqs. 4.1 and 4.2 are based upon the assumption of only extensional motion, i.e., bending effects are not included. Such effects have been shown by Humphreys and Winter (9) to be of little consequence for the application considered here.

A solution to Eqs. 4.1 and 4.2 has been obtained by linearizing the equations about the prestressed state. This state corresponds to the deformed position after application of the internal pressure. The resulting linearized equations are then solved using standard finite difference techniques for both the space and time variables. A Nemark-Beta stepforward solution method is used to determine the transient response. The organization of the code IMPSHELL is indicated in Table 4.1.

4.3 Data Input Format

Data is supplied to the computer code IMPSHELL by specifying certain information on the following punched cards:

1. Title card
2. Fluence card
3. Spectrum definition cards
4. Material identification card
5. Photoelectric cross-section cards
6. Shell geometry and internal pressure card
7. Structural property card
8. Time and print sequence card

If several problems are to be run sequentially, cards 1 through 8 should be prepared for each problem and stacked sequentially. Normal termination of a run stream is accomplished by placing an END card at the end of the stacked data deck. Details of data card preparation for cards 1 through 8 are contained in Table 4.2.

Table 4.1 ORGANIZATIONAL CHART FOR IMPSHELL

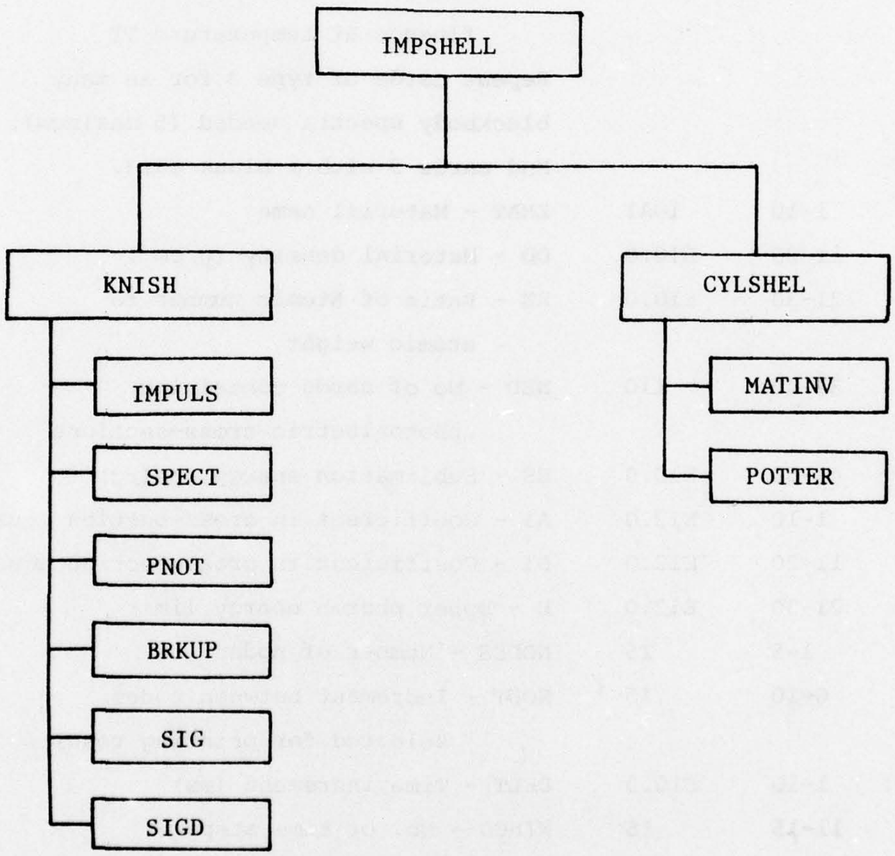


TABLE 4.2 DATA CARD DESCRIPTION FOR IMPSHELL

Card	Columns	Format	Data Item
1	1-80	80A1	TITLE - Any alphanumeric characters chosen to describe problem
2	1-10	E10.0	FLOONZ - Fluence (cal/cm^2)
	11-12	E10.0	SHINET - "Shine time" (μs)
3	1-10	E10.0	TT - Blackbody temperature (kev)
	11-12	E10.0	FF - Decimal fraction of total fluence at temperature TT
			Repeat cards of type 3 for as many blackbody spectra needed (5 maximum). End cards 3 with a blank card.
4	1-10	10A1	ZMAT - Material name
	11-20	E10.0	DD - Material density (g/cm^3)
	21-30	E10.0	ZZ - Ratio of Atomic number to atomic weight
	31-40	I10	NED - No of cards containing photoelectric cross-sections
	41-50	E10.0	ES - Sublimation energy (cal/g)
5	1-10	E12.0	A1 - Coefficient in cross-section equation
	11-20	E12.0	B1 - Coefficient in cross-section equation
	21-30	E12.0	U - Upper photon energy limit
6	1-5	I5	NODES - Number of nodes
	6-10	I5	NOUT - Increment between nodes selected for printing results
7	1-10	F10.0	DELT - Time increment (ms)
	11-15	I5	NINCS - No. of time steps
	16-20	I5	DELP - Time steps between each print command.
8	1-10	F10.0	PINT - Internal pressure (KN/m^2)

Card	Columns	Format	Data Item
9	1-15	F15.0	R - Shell radius (cm)
	16-30	F15.0	H - Shell thickness (cm)
	31-45	F15.0	E - Young's modulus (GN/m^2)
	46-60	F15.0	ANU - Poisson's ratio
	61-75	F15.0	RHO - Density (g/cm^3)

4.4 Sample Problem

To illustrate the data preparation steps, consider the problem of a cylindrical aluminum shell, 40 cm in radius, 0.6 cm thick, and pressurized internally by a pressure of 6895 KN/m^2 subjected to the energy flux from a 5 kev nuclear weapon detonation such that the fluence is 75 cal/cm^2. The weapon "shine time" is 300 microseconds. Young's modulus for the aluminum is 68.95 GN/m^2, Poisson's ratio is 0.3, and the density is 2.71 g/cm^3. The data cards required to execute IMPSHELL for this problem are listed in Table 4.3.

As mentioned previously, IMPSHELL computes the displacements, stresses, and strains in the cylindrical shell as a function of time. The values at each node around the shell are printed at the frequency specified by the value of DELP. The results of the sample problem described above are presented in Table 4.4.

```
   IMPSHELL SAMPLE PROBLEM. 7075 AL CYLINDER. 75 CAL/CM2. 5 KEV BB
    75          300
5           1

AL 7079   2 70           0 4814            30    3065
  0 16772D 04-0 26673D 01 0 10430D 01                          AL7079
  0 17603D 04-0 26643D 01 0 10990D 01                          AL7079
  0 22021D 04-0 26668D 01 0 11950D 01                          AL7079
  0 25072D 04-0 26611D 01 0 13040D 01                          AL7079
  0 27832D 04-0 26198D 01 0 15000D 01                          AL7079
  0 27606D 04-0 25997D 01 0 15590D 01                          AL7079
  0 11891D 05-0 24275D 01 0 20000D 01                          AL7079
  0 13063D 05-0 25632D 01 0 30000D 01                          AL7079
  0 15055D 05-0 26924D 01 0 40000D 01                          AL7079
  0 16924D 05-0 27768D 01 0 50000D 01                          AL7079
  0 18714D 05-0 28393D 01 0 59880D 01                          AL7079
  0 18892D 05-0 28396D 01 0 60000D 01                          AL7079
  0 21138D 05-0 29021D 01 0 65390D 01                          AL7079
  0 21259D 05-0 29005D 01 0 80000D 01                          AL7079
  0 24191D 05-0 29627D 01 0 89780D 01                          AL7079
  0 25933D 05-0 28429D 01 0 96580D 01                          AL7079
  0 25142D 05-0 28068D 01 0 10000D 02                          AL7079
  0 33845D 05-0 28658D 01 0 15000D 02                          AL7079
  0 40939D 05-0 29361D 01 0 20000D 02                          AL7079
  0 48263D 05-0 29910D 01 0 30000D 02                          AL7079
  0 55388D 05-0 30315D 01 0 40000D 02                          AL7079
  0 59471D 05-0 30508D 01 0 50000D 02                          AL7079
  0 61331D 05-0 30586D 01 0 60000D 02                          AL7079
  0 62235D 05-0 30622D 01 0 80000D 02                          AL7079
  0 60576D 05-0 30560D 01 0 10000D 03                          AL7079
  0 55032D 05-0 30352D 01 0 15000D 03                          AL7079
  0 45539D 05-0 29974D 01 0 20000D 03                          AL7079
  0 33501D 05-0 29395D 01 0 30000D 03                          AL7079
  0 21823D 05-0 28643D 01 0 40000D 03                          AL7079
  0 14537D 05-0 27965D 01 0 50000D 03                          AL7079
    62   30
0 1         4  1
6895
40          0 6           68.95           0 3          2 71
END
END DATA
>
```

Table 4.3 DATA CARDS TO EXECUTE IMPSHELL SAMPLE PROBLEM

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```
********************** PROGRAM IMPSHELL ************************

***** DEVELOPED BY THOMAS L COST. ATHENA ENGINEERING COMPANY *****

*****************************************************************

PROBLEM TITLE    IMPSHELL SAMPLE PROBLEM. 7079 AL CYLINDER. 75 CAL/CM2. 5 KEV BB

 THE FLUENCE FOR THIS PROBLEM IS        75000+02 CAL/CM**2

 THE UPPER BOUNDARIES ON THE HISTOGRAM ARE

  50000+00    10000+01    15000+01    20000+01    25000+01    35833+01    46667+01    57500+01
  68333+01    79167+01    90000+01    10083+02    11167+02    12250+02    13333+02    14417+02
  15500+02    16583+02    17667+02    18750+02    19833+02    20917+02    22000+02    23083+02
  24167+02    25250+02    26333+02    27417+02    28500+02    29583+02    30667+02    31750+02
  32833+02    33917+02    35000+02    37500+02    40000+02    42500+02    45000+02    47500+02
  50000+02    55000+02    60000+02    65000+02    70000+02    75000+02    80000+02    85000+02
  90000+02    15000+03

 BLACK BODY SPECTRUM. TEMPERATURES AND RELATIVE WEIGHTS ARE
  50000+01    10000+01

 THIS PROBLEM CONSISTS OF   1 ZONES AS FOLLOWS
ZONE NO       MATERIAL        FAR DEPTH   THICKNESS  DENSITY        Z/A        NO. EDGES
  1           AL 7079          1000+00     1000+00    2700+01      4814+00        30

        DOSE DEPTH              DOSE     PRIMARY COMPONENT SCATTERED COMPONENT

         10000-04             31899+04            31852+04            46577+01
         20000-04             30906+04            30858+04            46750+01
         30000-04             30231+04            30184+04            46908+01
         40000-04             29638+04            29591+04            47054+01
         50000-04             29084+04            29037+04            47188+01
         60000-04             28561+04            28513+04            47315+01
         70000-04             28065+04            28018+04            47434+01
         80000-04             27595+04            27548+04            47548+01
         90000-04             27149+04            27101+04            47653+01
         10000-03             26725+04            26678+04            47756+01
         12000-03             25939+04            25891+04            47948+01
         14000-03             25225+04            25176+04            48127+01
         16000-03             24574+04            24525+04            48295+01
         18000-03             23978+04            23930+04            48454+01
         20000-03             23431+04            23383+04            48605+01
         22000-03             22927+04            22878+04            48750+01
         24000-03             22461+04            22412+04            48888+01
         26000-03             22029+04            21980+04            49022+01
         28000-03             21626+04            21577+04            49150+01
         30000-03             21250+04            21201+04            49275+01
```

Table 4.4 OUTPUT FROM IMPSHELL SAMPLE PROBLEM

```
      .32000-03        .20898+04        .20848+04        .49395+01
      .34000-03        .20567+04        .20517+04        .49512+01
      .36000-03        .20255+04        .20205+04        .49625+01
      .38000-03        .19961+04        .19911+04        .49735+01
      .40000-03        .19682+04        .19633+04        .49843+01
      .50000-03        .18482+04        .18431+04        .50342+01
      .60000-03        .17517+04        .17467+04        .50789+01
      .70000-03        .16716+04        .16665+04        .51193+01
      .80000-03        .16033+04        .15981+04        .51562+01
      .90000-03        .15439+04        .15387+04        .51899+01
      .10000-02        .14916+04        .14863+04        .52210+01
      .20000-02        .11649+04        .11595+04        .54304+01
      .30000-02        .98619+03        .99067+03        .55268+01
      .40000-02        .86372+03        .85816+03        .55605+01
      .50000-02        .77130+03        .76575+03        .55558+01
      .60000-02        .69769+03        .69217+03        .55267+01
      .70000-02        .63699+03        .63151+03        .54817+01
      .80000-02        .58670+03        .58028+03        .54262+01
      .90000-02        .54161+03        .53625+03        .53641+01
      .10000-01        .50321+03        .49791+03        .52977+01
      .20000-01        .28364+03        .27893+03        .46156+01
      .30000-01        .18954+03        .18548+03        .40615+01
      .40000-01        .13929+03        .13570+03        .35942+01
      .50000-01        .10849+03        .10528+03        .32051+01
      .60000-01        .87725+02        .84967+02        .28583+01
      .70000-01        .72780+02        .70245+02        .25354+01
      .80000-01        .61505+02        .59285+02        .22200+01
      .90000-01        .52686+02        .50795+02        .18914+01
      .10000+00        .45564+02        .44050+02        .15141+01

  IMPULSE DESCRIPTION

  SUBLIMATION LAYER THICKNESS (CM)=               .00002000
  IMPULSE (TAPS)                   =             4.00753045
  IMPULSE (N-MICROSECONDS/M2)      =        400753.04296875
  MAXIMUM PRESSURE (N/M2)          =          2671.68695068

 *** DYNAMIC RESPONSE OF A CIRCULAR CYLINDER ***


 PROBLEM TITLE >  IMPSHELL SAMPLE PROBLEM. 7079 AL CYLINDER. 75 CAL/CM2. 5 KEV BB


      NUMBER OF NODES              =      62
      NUMBER OF TIME INCREMENTS    =       4
      BLAST LOADING TIME           =        .00030000
      TIME STEP                    =        .00010000
      INTERNAL PRESSURE            =       6.89499998
      CYLINDER RADIUS              =        .40000000
      BLAST LOAD MAGNITUDE         =    2671.68695068
      NODAL POINT OUTPUT FREQUENCY =      30
      SHELL THICKNESS              =        .00600000
      MODULUS OF ELASTICITY        =  68949999616.
      POISSON'S RATIO              =        .30000000
      MATERIAL DENSITY             =        .00000271
      SOLUTION OUTPUT FREQUENCY    =       1
      I/O TYPE - REAL(0) OR NORM(1)=       0
```

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Table 4.4 (continued)

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TIME = .00000000 INCREMENT = 1

NODE	THETA	V-DISP	U-DISP	V-VEL	U-VEL	STRESS	STRAIN
1	.00	-.15300874-04	-.58877860-03	-.11010063-18	-.42330357-15	-.10301384+06	-.14940330-05
31	88.52	.42141916-03	.10210020-03	.30145377-15	.13742076-15	-.10255827+06	-.14874296-05
61	177.05	.14120625-07	.19813189-04	.10107344-19	.14029902-16	-.10223384+06	-.14827843-05

TIME = .00010000 INCREMENT = 2

NODE	THETA	V-DISP	U-DISP	V-VEL	U-VEL	STRESS	STRAIN
1	.00	.30490236-05	.14711974-03	.24784730-16	.95243303-15	.25769948+05	.37374834-06
31	88.52	-.10630763-03	-.47995568-04	-.67823722-15	-.30917416-15	.25621512+06	.37159553-06
61	177.05	-.35316503-08	-.49016737-05	-.22740984-19	-.31566117-16	.25552994+05	.37060179-06

TIME = .00020000 INCREMENT = 3

NODE	THETA	V-DISP	U-DISP	V-VEL	U-VEL	STRESS	STRAIN
1	.00	-.76984354-05	-.29433076-03	-.33044256-16	-.12726956-14	-.51547614+05	-.74760861-06
31	88.52	.21073116-03	.96003369-04	.90430921-15	.41218087-15	-.51263698+06	-.74349090-06
61	177.05	.70686563-08	.98098760-05	.30323699-19	.42089727-16	-.51144711+05	-.74178521-06

TIME = .00030000 INCREMENT = 4

NODE	THETA	V-DISP	U-DISP	V-VEL	U-VEL	STRESS	STRAIN
1	.00	.76981215-05	.29431875-03	.44057871-16	.16959992-14	.51545960+05	.74758463-06
31	88.52	-.21072208-03	-.95999984-04	-.12057872-14	-.54952651-15	.51249640+05	.74328702-06
61	177.05	-.70684336-08	-.98094506-05	-.40436379-19	-.56124011-16	.51143088+05	.74174187-06

END DATA
>

Table 4.4 (continued)

5. CORRELATION OF EXPLODING FOIL IMPULSE TESTING WITH NUCLEAR EFFECTS LOADS

The impulsive loads produced by sublimation effects of nuclear weapons is often simulated in the laboratory by the use of "exploding foil" techniques (10). In such test programs, thin films of metallic foils are bonded to the structural surface which experiences the impulsive loads. Large doses of electrical energy are discharged into the conducting foils from capacitor banks resulting in sublimation of the foil material. This sublimation, in turn, loads the structure impulsively. It is desirable to be able to correlate the simulation loads produced by the exploding foil techniques with the actual loads produced by nuclear weapon effects.

One procedure for correlating the results of the two phenomena is based on the equivalence of deposited energy and total impulse. It is assumed that the source of energy is unimportant and only the amount of energy deposited in the sublimated layer affects the impulse. Action times of the two effects are assumed to be approximately the same.

The procedure for calculating the impulsive loads due to nuclear weapon effects has been described in detail in Section 2.1. This procedure involves first determining the energy deposition profile in the material due to exposure to radiant energy from a nuclear weapon. This profile is calculated using an energy deposition code such as KNISH. After the profile is known, the total impulse is calculated using the Whitener model described in Section 2.1. A calculation which yields the total impulse per unit area (taps/cm^2) produced by the nuclear weapon effects.

To calculate the impulse produced by an exploding foil, use is made of the single-zone approximate method for impulse calculation defined as

$$I_B = 9150\, \rho h \sqrt{E_d - E_s} \qquad (5.1)$$

where

I_B = impulse per unit area of foil (taps/cm^2)

ρ = material density (g/cm^3)

h = foil thickness (cm)

E_d = energy density in foil from capacitor discharge (cal/g)

E_s = sublimation energy of material (cal/g)

To use Eq. 5.1 to calculate the impulse produced by an exploding foil, assume the known total amount of energy discharged by the capacitor bank, minus any losses, is deposited uniformly throughout the foil. This allows an energy density E_d to be calculated by dividing the net deposited energy by the number of grams of foil used. Substitution of E_d into Eq. 5.1, along with the thickness h and the material properties ρ and E_s, allows the impulse per unit area to be calculated.

Conversely, if the impulse produced by a given nuclear effects loading is known, the energy density required by the exploding foil technique to produce a similar impulse can be determined by solving Eq. 5.1 for E_d, i.e.,

$$E_d = E_s + \left[\frac{I_B}{9150\rho h} \right]^2 \tag{5.2}$$

Eq. 5.2 has been evaluated for the particular case of aluminum (E_s = 3200 cal/gm, ρ = 2.71 gm/cm^3) for different thicknesses and the results presented graphically in Figure 5.1. This illustration permits a rapid determination to be made of the energy density requirements to simulate the results for a particular nuclear effects produced impulsive load.

As an example of how to use this information, assume that it is desired to simulate a nuclear explosive which produced an impulsive load of 1000 taps/cm^2. The foil material to be sublimated is aluminum with ρ = 2.71g/cm^3 and E_s =3200 cal/g and is 0.0508 mm thick. Evaluating Eq. 5.2 gives a value for E_d of 3263 cal/g required to sublimate

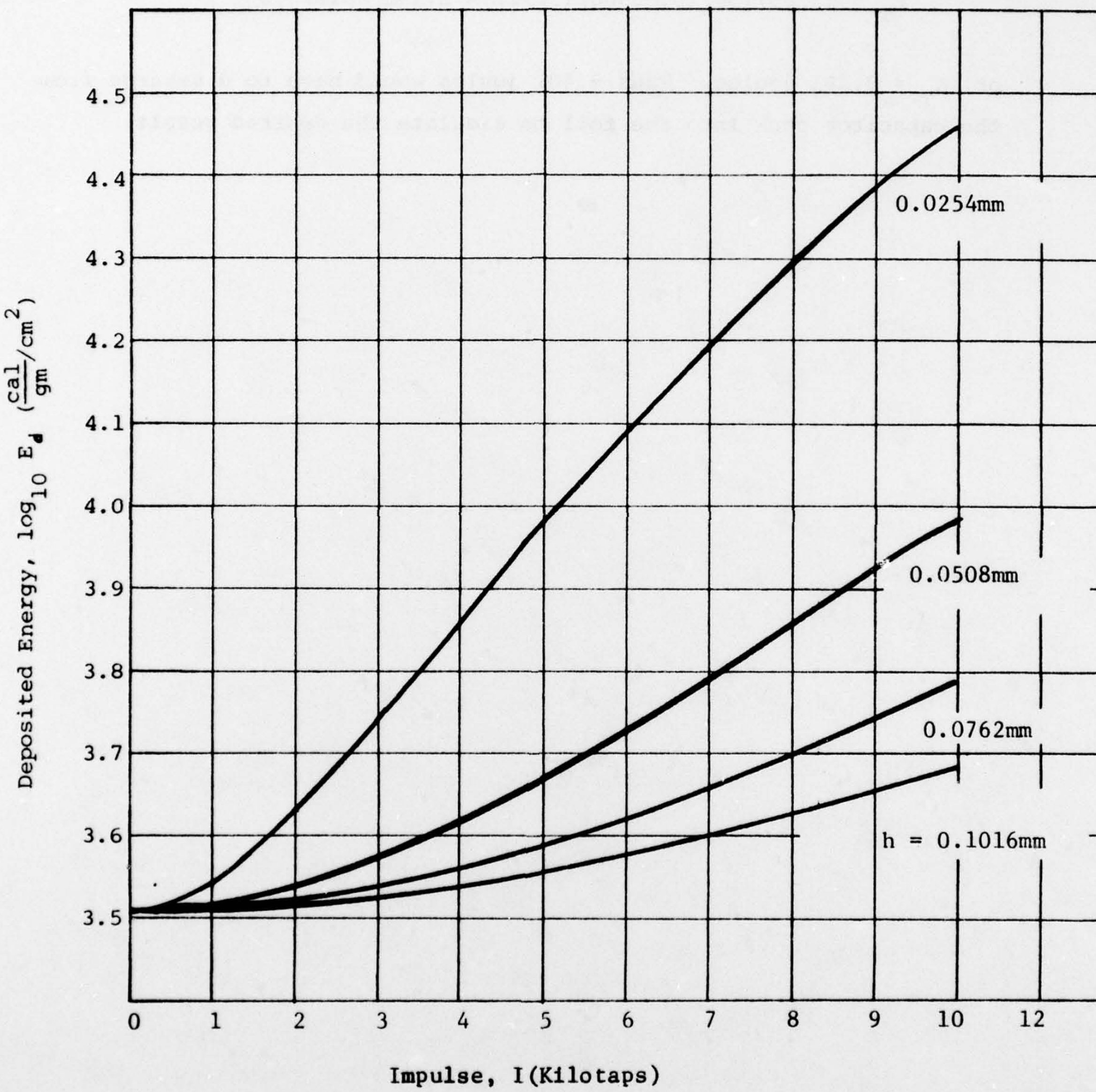

Figure 5.1. Correlation of Impulse and Deposited Energy

the foil at the desired impulse level. If the structural surface area to be loaded impulsively is 50 cm^2, the total energy requirement is

$$E_T = (3263)(50)(0.00508)(2.71) = 2{,}246 \text{ calories}$$

or, E_T = 9,401 joules. Thus 9,401 joules would have to discharge from the capacitor bank into the foil to simulate the desired result.

6. CLOSING REMARKS

The computer codes described in this report were designed to meet a particular need of the project sponsor. No attempt was made to create general purpose computer codes capable of assessing the spectrum of problems associated with the response of structures to electromagnetic radiation from a nuclear weapon. The codes serve the purpose for which they were intended: correlating specific experimental measurements with specific mathematical models. However, due to limitations placed on the models, the codes are not presently capable of assessing the vulnerability or survivability of missle structures. Still further code developments are needed to address these problems. The codes should be extended to include the following characteristics to make them more accurate:

1. <u>material property dependence on temperature</u>
   At the high temperatures in question the material stiffness is decreased significantly which, in turn, significantly affects the structural response.
2. <u>large deformation effects</u>
   The loads produced by nuclear weapon effects are sufficiently severe that large deformations are experienced before the structure fails.
3. <u>failure criteria</u>
   Missile structures can withstand some permanent damage before failure occurs. The specific details of structural failure is important.
4. <u>elastic-plastic material behavior</u>
   Material yielding and plastic deformations occur before the structure fails.

5. <u>combined blast, impulsive, and operational loads</u>
   The operational loads produced by acceleration and pressurization are high as well as the blast and impulsive loads produced by nuclear weapon effects. The combined effects of all loads produces failure.
6. <u>arbitrary geometrical shapes</u>
   More complex geometries than plates and cylinders must be evaluated.
7. <u>composite material response</u>
   The response of layered, reinforced, composite materials to nuclear effects loads is important.

Each of these items is important in evaluating missile structural integrity and should be included in survivability/vulnerability studies.

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